Optimizing the logistics of production, harvest, procurement, storage, and transportation of lignocellulosic biomass for conversion to ethanol

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Introduction

The US ethanol industry is starch-based (primarily corn grain). Conversion technologies used in the starch-based system are approaching their inherent theoretical limits.[1] In the absence of subsidies and/or mandates that ethanol blends be used to satisfy octane and oxygenate levels, the starch-based ethanol industry may not be economically viable.[1] The National Research Council has suggested that a reasonable goal for ethanol research and development programs is to produce technology that will enable production of products that are cost competitive with petroleum-based alternatives. Conversion of lignocellulosic biomass such as crop residue (corn stover, wheat straw) and perennial grasses is theoretically much more efficient than conversion of corn grain.[1, 2, 3, 4] A lignocellulosic-based system could use virtually all of the harvested plant material, could use feedstock produced on less productive land, and could use material that would ordinarily be considered waste, such as waste from wood products processing and crop residue.[5, 6, 7, 8, 9, 10]

While theoretically more efficient, conversion of lignocellulosic biomass to ethanol is not without major challenges. Relative to corn grain, it is bulky and difficult to transport. It is relatively simple for corn grain to ethanol plants to obtain feedstock. They may post a competitive price and corn grain will be delivered by the existing marketing system. Corn grain is also relatively easy to store. Managers of corn grain to ethanol plants may use existing futures markets to manage feedstock price risk. These options would not be available to managers of a lignocellulosic biomass to ethanol conversion facility.

For a conversion ratio of 75 gallons of ethanol per ton of biomass, a 100 million gallons per year conversion facility would require one and one-third million tons of biomass. A total of 224 truckloads of 17 dry tons of biomass would be required per day, assuming 350 operating days per year. Prior to investing in a conversion facility, it is likely that arrangements would be made to assure a reliable flow of feedstock. This could be done through contracts with individual growers, or with a group of growers through a cooperative arrangement, or through long-term land leases similar to those employed by the federal government with the conservation reserve program. In addition to assuring feedstock quantities and quality, a plan for providing a steady flow of feedstock to the conversion facility is needed. The logistics of feedstock production, harvest, storage, transport, and delivery could be challenging.

Objective

An integrated model that encompasses alternative feedstocks, feedstock production, harvest, storage, transport, processing, by-products from conversion, plant size, and plant location, could be used to identify key cost components, potential bottlenecks, and reveal opportunities for reducing costs and prioritizing research. The overall objective of the research reported in this paper is to develop an integrative framework for determining the economic feasibility of an agricultural lignocellulosic biomass-to-ethanol industry. The specific objective was to determine for a given case study area the number, size and distribution of biomass-to-ethanol processing capacity that maximizes industry net present worth, the optimum quantities of biomass stocks and flows, and the most important cost items in the system. The model is designed to determine the most economical source of biomass, fertility level, structure of the biomass production component, timing of harvest and storage, inventory management, conversion plant sizes, and locations.

Although abundant literature exists on biomass-to-ethanol industry appraisal, virtually none pay adequate attention to the logistics associated with raw material production, transportation, and storage and inventory management. By assuming fixed quantities of ready-to-deliver raw materials at each prospective supply point, most plant location studies ignore the challenges and tradeoffs associated with performing these functions.

Method

The current research develops and demonstrates application of an integrative approach for determining the technical and economic viability of investment in a biomass-to-ethanol industry. With industry net present worth as a decision criterion, the model is designed to use mixed integer mathematical programming to determine the optimum number, size and location of processing plants for a case study region. In addition to explicit modeling and optimization of production, storage, transportation, and processing activities, the model also incorporates the tradeoff between field losses and storage losses as part of the harvest timing decision process. The model also permits the identification of key parameters and sensitivity analysis on these parameters.

Conclusion

Data were acquired and the model applied to a specific region in which the potential alternative feedstocks include crop residue (corn stover, wheat straw), native prairie grasses, introduced forage grasses, and switchgrass. The base model was solved for the case study region. Given the assumptions and data used for the base model, it was determined that the optimal strategy would include a combination of the potential feedstocks. The logistics of production, harvest, procurement, storage, and transportation of feedstocks to the conversion facility as determined by the model provide insight as to how an ethanol industry based upon lignocellulosic biomass feedstocks might be structured.

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